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EFFECTS OF FORCE MODEL ERRORS ON SEASAT SATELLITE ORBITS,(U)
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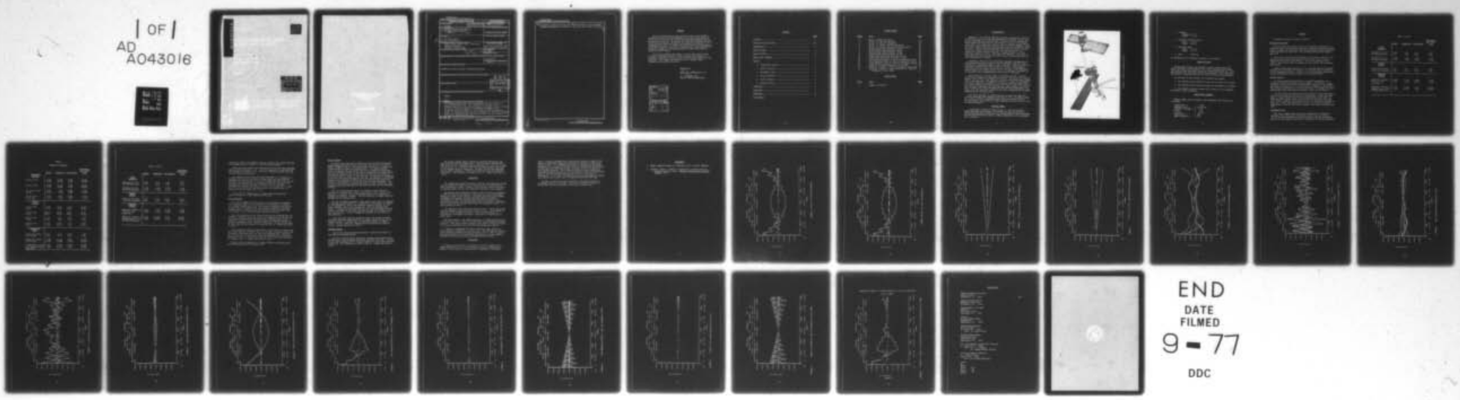

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SEASAT

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

(U) Simulated SEASAT orbit data are generated under the influence of several perturbing forces. Least squares fits are made to the simulated data and the results are examined in relation to the feasibility of long arc (24 hours) ephemeris determination of SEASAT orbits. Perturbing forces considered are: (1) truncated earth's gravitation fields; (2) atmospheric drag; (3) solar radiation; (4) the earth's visible albedo. The orbit generation integration interval was also examined for truncation or round-off errors.

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cont. Results indicate that the error "build-up" renders long arc SEASAT ephemeris determination infeasible at the orbit error level of one meter.

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FORWORD

One of the objectives of the projected launch of the SEASAT-A satellite in 1978 is the determination of the mean ocean surface to 10 cm accuracy with the use of radar altimetry measurements from the satellite to the ocean. To achieve this precision, accurate positions of the satellite must be obtained using external tracking data. A reasonable objective is to obtain the radial position of the satellite to one meter accuracy, and then use observations of discrepancies in altimetric heights of intersecting orbits to reduce this error to around this 10 cm level.

This report examines the effects of force field errors on the accuracy of computed satellite orbits to assess the prospects of achieving a one meter accuracy in the computed radial position of the satellite. This report was reviewed by R. J. Anderle, Head, Astronautics and Geodesy Division.

RELEASED BY:

Ralph A. Niemann

R. A. NIEMANN, Head
Warfare Analysis Department

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FIGURE LISTING

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INTRODUCTION

SEASAT is a low altitude (800 km) satellite scheduled for launch by the National Aeronautics and Space Administration (NASA) in 1978. One purpose of SEASAT is to provide radar altimeter data for determining geoid heights and deflections of the vertical over much of the earth's ocean area. This application requires that the radial component of the satellite position, measured from the earth's center, be known to within one meter. Radial error is emphasized throughout the results section, since it is a direct indicator of the error associated with the satellite's radial position component. Tangential error is a more sensitive indicator of error. Both should be examined, especially in cases where the radial errors are small, since the errors may alias if the tracking data is limited.

In general, short arc (1-2 revolutions) ephemeris determination is desirable because greater accuracy can be obtained, since less error "build-up" is experienced within a short time span. Effective short arc computation requires that data be taken at several points within a revolution, the more points the better the accuracy. Since NASA has a limited number of tracking stations, short arc ephemeris for SEASAT is not feasible unless supplementary tracking data are obtained.

Where there are a limited number of tracking stations, long arc (24-48 hours) ephemeris is generally necessary. The success of long arc depends on the orbit error "build-up" caused by perturbing forces acting over a long time span. The method used herein to assess the feasibility of long arc ephemeris for SEASAT is to generate simulated SEASAT orbit data under several perturbing conditions and "least-square" fit state-of-the-art models (reference (1)) to these data under optimum conditions (e.g. no data noise, data uniformly distributed along trajectory). The effect of error "build-up" can then be assessed by examining the residuals produced by the fitting process.

This report presents in separate results sections the "post fit" residuals obtained under changing conditions of orbit integration interval, earth's gravity, atmospheric drag, radiation pressure and the earth's albedo. Conclusions are drawn regarding the feasibility of long arc SEASAT ephemeris.

PHYSICAL MODEL

A photograph of SEASAT is shown in fig. 1. For this analysis, SEASAT was physically modeled as a cylinder and three flat plates, representing the Agena rocket body, the large synthetic aperture antenna and two sun seeking solar panels. Nominal dimensions of the components are as follows:

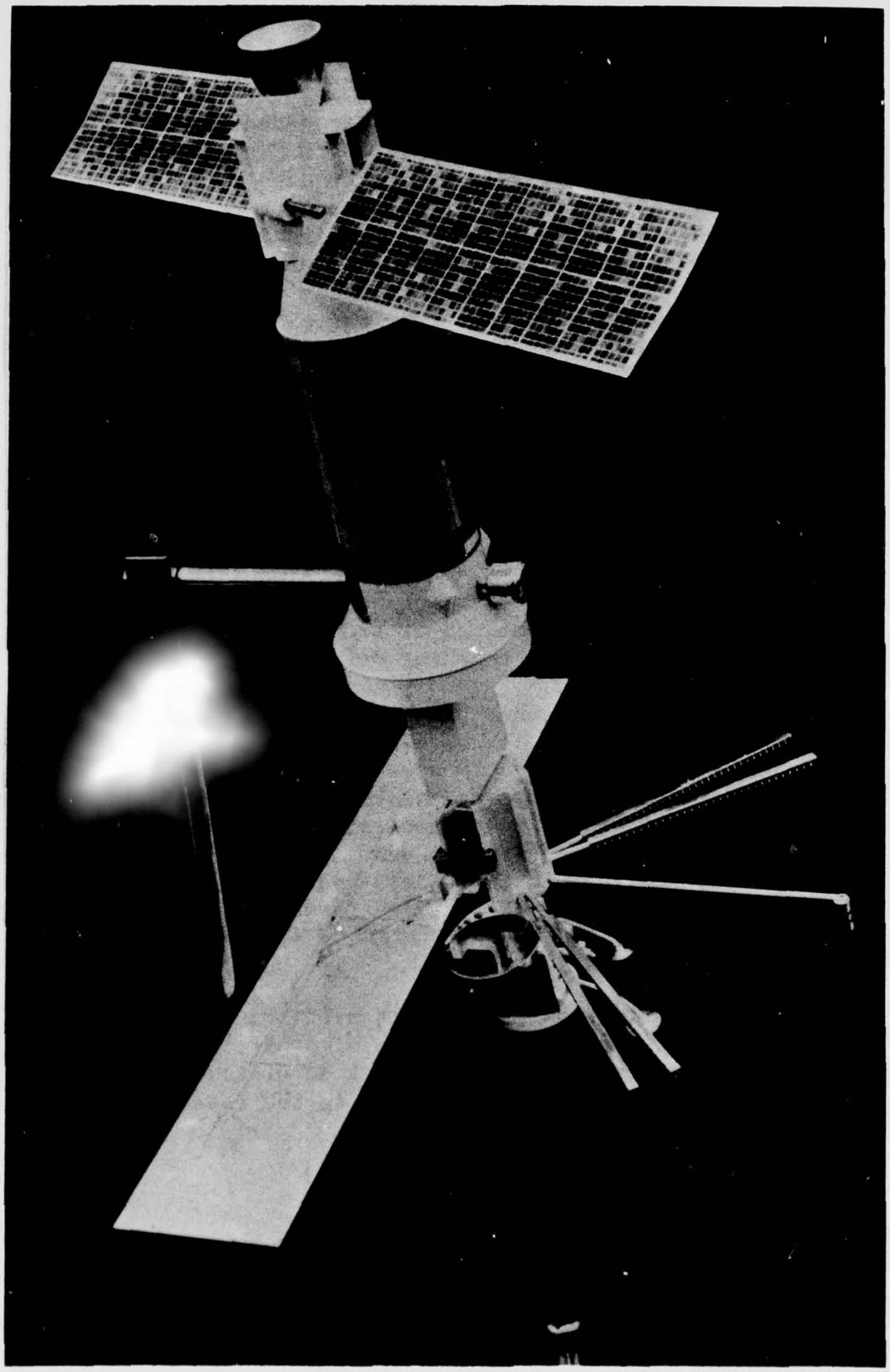

FIGURE 1 SEASAT of SEASAT Satellite

1. cylinder
   diameter = 1.5 m
   length = 9.1 m

2. synthetic aperture antenna
   width = 2.0 m
   length = 14.0 m

3. one solar panel
   width = 1.2 m
   length = 6.1 m

4. mass = 1877 kg

No shielding of one component by another is considered.

SEASAT ATTITUDE

During normal flight, the synthetic aperture antenna faces the earth's surface, the longitudinal axis of the cylinder points toward the earth and the solar panel faces are directed toward the sun. Thus the cylinder flies broadside through the atmosphere. This attitude is held within a specified tolerance by on-board stabilization equipment.

For purposes of this analysis the following are assumed:

1. The cylinder points toward the center of the earth at all times.

2. The cylinder flies broadside through the atmosphere at all times.

3. The synthetic aperture antenna flies edge-on to the atmosphere and offers no drag resistance.

SEASAT ORBIT ELEMENTS

Nominal SEASAT orbit parameters used throughout this analysis are as follows:

eccentricity, e	=	0.001
semi-major axis, a	=	7178.145 km
argument of perigee, ω	=	0.0°
$e \sin \omega$	=	0.0
$e \cos \omega$	=	0.001
inclination, i	=	108°
right ascension, Ω	=	257°

RESULTS

A summary of results is given in Table 1.

Integration Interval

To insure that the results would not be affected by truncation or round-off errors from the orbit generation numerical integration routine, orbits including all perturbing forces were generated using integration intervals of 30 sec and 60 sec. The resulting residuals are shown in figs. 2-5.

It is seen that the maximum difference in residuals from the 30 sec and 60 sec cases versus each case's best fit orbit (figs. 2 and 3 respectively) is only one centimeter. The 30 sec and 60 sec unfit (fig. 4) and best fit (fig. 5) comparisons also exhibit one centimeter differences.

Based on these small residuals, it is concluded that the following results are not affected by truncation or round-off errors introduced by the integration routine. Further, a 60 sec integration interval was used in the generation and fitting of all subsequent orbits.

Earth's Gravity

The earth's gravitation potential is normally expressed as an associated spherical harmonic series of degree n and order m. Using synthetic values of the constant coefficients obtained by the procedure discussed in reference (2), a gravity field of degree 25 and order 25 was assumed to represent the true gravity field. No attempt was made to remove terms which could produce resonance effects in the orbits.

The 25/25 field was truncated to 12/12 and 20/20 by setting equal to zero all coefficients above 12 and 20 respectively. Orbits over time spans of two revolutions and 24 hours were generated using both the 12/12 and 20/20 fields. Best fits were made to these data using the 25/25 field to produce the reference orbit. The residuals are shown in figs. 6-9. Radial rms errors are 4.58, 14.57, 0.47 and 2.41 meters respectively. Only the six orbital elements were improved during these fits.

Atmospheric Drag

The area of SEASAT presented to the atmosphere for purposes of computing drag effects was a combination of two parts as follows: (1) the constant broadside area of the cylinder; and (2) the varying area of the sun seeking solar panels, governed by the relative position

Table 1 (cont')

	Radial	Tangential	Out-of-Plane	rms meters Peak meters Total
Solar Radiation				
Radiation vs 2 rev fit 50% reflection	0.09 0.20	0.18 0.43	0.01 0.01	0.20 0.44
Radiation vs 24 hr fit 100% reflection	1.160 2.756	2.263 5.324	0.073 0.175	2.544 5.424
Earth's Albedo				
Albedo vs No Albedo 2 rev 50% reflection	0.04 0.09	0.18 0.39	0.00 0.00	0.18 0.39
Combined Effects				
Radiation + Albedo vs 24 hr fit 100% reflection	1.333 3.169	2.602 6.114	0.078 0.188	2.925 6.228
Radiation + Albedo + 4 Segment Drag vs 24 hr fit 100% reflection	1.421 4.450	12.430 36.769	0.127 0.292	12.511 36.924

TABLE 1

SUMMARY OF RESIDUALS

	Radial	Tangential	Out-of-Plane	rms meters peak meters Total
Integration Interval				
30 sec vs fit	1.469 4.065	12.434 28.783	0.089 0.211	12.520 28.785
60 sec vs fit	1.468 4.041	12.442 28.803	0.089 0.209	12.529 28.805
30 sec vs 60 sec no fit	0.041 0.094	2.433 4.234	0.003 0.007	2.434 4.235
30 sec fit vs 60 sec fit	0.037 0.061	2.423 4.158	0.001 0.002	2.423 4.158
Earth's Gravity				
12/12 vs fit 2 rev	4.58 9.93	9.22 23.03	4.65 12.59	11.30 24.52
12/12 vs fit 24 hr	14.57 33.67	33.50 93.49	10.86 29.53	38.11 93.52
20/20 vs fit 2 rev	0.47 0.98	1.11 3.05	0.93 1.99	1.52 3.35
20/20 vs fit 24 hr	2.41 5.40	11.06 22.91	2.13 4.87	11.52 22.99
Atmospheric Drag				
Single Drag Coeff. vs 2 rev fit	0.21 0.43	0.55 1.17	0.00 0.01	0.59 1.24
Single Drag Coeff. vs 24 hr fit	0.738 1.522	12.124 27.089	0.011 0.029	12.146 27.132
4 Drag Coeff vs 24 hr fit--Improved single drag coeff.	1.531 4.563	12.946 44.717	0.094 0.207	13.036 44.943

Table 1 (cont')

	Radial	Tangential	Out-of-Plane	rms meters Peak meters Total
Solar Radiation				
Radiation vs 2 rev fit 50% reflection	0.09 0.20	0.18 0.43	0.01 0.01	0.20 0.44
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Radiation + Albedo vs 24 hr fit 100% reflection	1.333 3.169	2.602 6.114	0.078 0.188	2.925 6.228
Radiation + Albedo + 4 Segment Drag vs 24 hr fit 100% reflection	1.421 4.450	12.430 36.769	0.127 0.292	12.511 36.924

of the sun. Again, the synthetic aperture antenna flies edge-on through the atmosphere and is assumed to offer no drag resistance.

Orbits over time spans of two revolutions and 24 hours were generated using a drag coefficient of 2.0. Best fits were made to these data and the residuals are shown in figs. 10 and 11. Radial rms errors are 0.21 and 0.74 meters respectively.

Past experience has shown the drag coefficient of a satellite (i.e. the best fit value of the product of drag coefficient and satellite presented area) to vary by as much as 50 percent from day to day at this altitude. To simulate this as a possible variation, a 24 hour orbit was generated, letting the drag coefficient vary in 10 percent increments at six hour intervals (i.e. 2.0, 2.2, 2.4 and 2.6). A best fit was made to these data and the residuals are shown in fig. 12. Radial rms error is seen to be 1.53 m.

The six orbital elements plus a single drag coefficient were improved during all of the atmospheric drag fits.

Solar Radiation

The area of SEASAT presented to the sun for purposes of computing solar radiation effects was a combination of three parts as follows: (1) constant maximum area of the solar panels, assumed to face the sun at all times; (2) cylinder area, varying as the satellite's attitude changes relative to the sun; and (3) synthetic aperture antenna area, also varying as its attitude changes relative to the sun.

The solar radiation can be either absorbed by or reflected from the satellite. Normally, the total effect is a combination of the two, the fraction of each determined by the physical characteristics of the satellite's surface. A two revolution orbit was generated using a 50 percent absorbed/50 percent reflected combination. A best fit was made to these data and the residuals are shown in fig. 13. Radial rms error is 0.09 m.

Since reflected radiation exerts twice as much force on a given area as an equal amount of radiation which is absorbed, the worst case is the 100 percent reflection case. An orbit was generated over a time span of 24 hours using a 100 percent reflection coefficient to illustrate a worst case effect. A best fit was made to these data and the residuals are shown in fig. 14. Radial rms error is 1.16 m.

The six orbital elements plus a single radiation coefficient were improved during the solar radiation fits.

Earth's Albedo

An albedo model developed by NSWC/DL for use in Global Positioning System related studies was used to simulate the effect of the earth's albedo on SEASAT's orbit. This model treats the earth as a sphere with uniform radiation reflection characteristics. The albedo pressure vector is computed at any satellite position by summing contributions from the reflecting portion of the sphere (governed by the angle between the position vectors of the sun and the satellite with the origin at the earth's center) visible to the satellite. The reflection coefficient of the earth was initially adjusted such that the magnitude of the albedo pressure at an altitude of 1000 km (on the earth-sun line) equals 20 percent of the magnitude of the direct solar radiation pressure in the vicinity of the earth, as has been observed for other satellites. This adjusted reflection coefficient of the earth was used for all subsequent analyses.

Once the albedo pressure vector is computed at the satellite's position, it is treated as a point source vector, just as direct solar radiation is treated. This is justified because of the cylindrical symmetry and attitude of SEASAT. The only exception is albedo radiation absorbed by the cylinder walls.

The area of SEASAT presented to the center of the earth for purposes of computing albedo effects was a combination of three parts as follows: (1) the maximum face area of the synthetic aperture antenna; (2) the end-on cylinder; and (3) the varying area of the sun seeking solar panels. It should be noted that the only time that the albedo pressure vector is entirely in the radial direction is when the satellite is on the earth-sun line. It has a tangential component at all other non-zero positions.

A two revolution orbit was generated using a 50 percent absorbed/ 50 percent reflected combination for the albedo pressure effect on the satellite areas. A similar orbit was generated without the albedo effect. The two orbits were compared and the residuals are shown in fig. 15. Radial rms error is 0.04 m.

Combined Effects

Two 24 hour orbits were generated which contained the effects of more than one perturbing force.

The first combined effects simulation included solar radiation and albedo effects, each assuming 100 percent radiation reflection. The best fit was made improving the six orbital elements plus the solar radiation coefficient. The residuals are shown in fig. 16. Radial rms error is 1.33 m.

The second combined effects simulation included atmospheric drag, solar radiation and the albedo effect. The drag effect included the same four six hour incremented drag coefficients (i.e. 2.0, 2.2, 2.4 and 2.6) as in fig. 12. The solar radiation and albedo effects were based on 100 percent radiation reflection. The best fit was made improving the six orbital elements, a single drag coefficient and the radiation coefficient. The residuals are shown in fig. 17. Radial rms error is 1.42 m.

DISCUSSION

The integration interval simulations show that the subsequent results are not affected by truncation or round-off errors introduced by the orbit integration routine. Further, they show that a 60 sec interval is an adequate sample rate for the frequencies inherent in the residuals.

The gravity field simulations indicate that, for long arc ephemeris, in order to reduce radial errors to the sub-meter level, coefficients higher than order 20 are required. Although a gravity field optimized for SEASAT could produce favorable aliasing effects of higher coefficients so that the accuracy might approach one meter, dense tracking for gravity field determination would be required to determine such a field, and the attempt would likely be defeated by errors in non-conservative forces.

The atmospheric drag simulations indicate that a variable presented area can produce a radial error of as much as 0.75 m. This assumes no variation in the atmospheric density. When variable density is realistically considered, drag error is expected to be above the one meter level.

The solar radiation and albedo simulations of combined effects show a 1.33 m radial error. This is for the worst case 100 percent reflected radiation. This error would be reduced, most likely to below one meter if the actual absorbtion and reflection percentages were applied.

It should be remembered that these simulations were carried out under optimistic conditions of perfect data. Most importantly, the data is distributed uniformly throughout the entire orbit. Even if perfect data were possible in the real SEASAT application, a limited number of tracking stations would preclude uniformly distributed data.

CONCLUSION

A radial orbit accuracy of one meter can not be achieved for the SEASAT satellite by orbit fits to 24 hours or more of observations because of the effects of uncertainties in knowledge of the gravity

field. Accurate representation of the gravity field for orders of the harmonic coefficients higher than 20 would be required to achieve one meter accuracy. Use of SEASAT observations to obtain a gravity field optimized for this application would likely be defeated by uncertainties in drag and solar radiation effects, and would in any case require a dense tracking network. While effects of drag and solar radiation on the computed radial position of the satellite are close to one meter for perfect, well distributed tracking data for fits to 24 hours of observations, it is likely that some aliasing of large tangential errors into radial errors would occur if limited tracking data were used.

In order to achieve one meter accuracy in the radial position of the SEASAT satellite, sufficient tracking data should be acquired to permit orbit fits to time spans on the order of three hours.

REFERENCES

1. CELEST Computer Program for Computing Satellite Orbits (NSWC/DL).

2. Malyevac, Carol W., "Effect of Truncation of Gravity Field on Computed Satellite Orbits", NSWC/DL Technical Report TR-2373, September 1970.

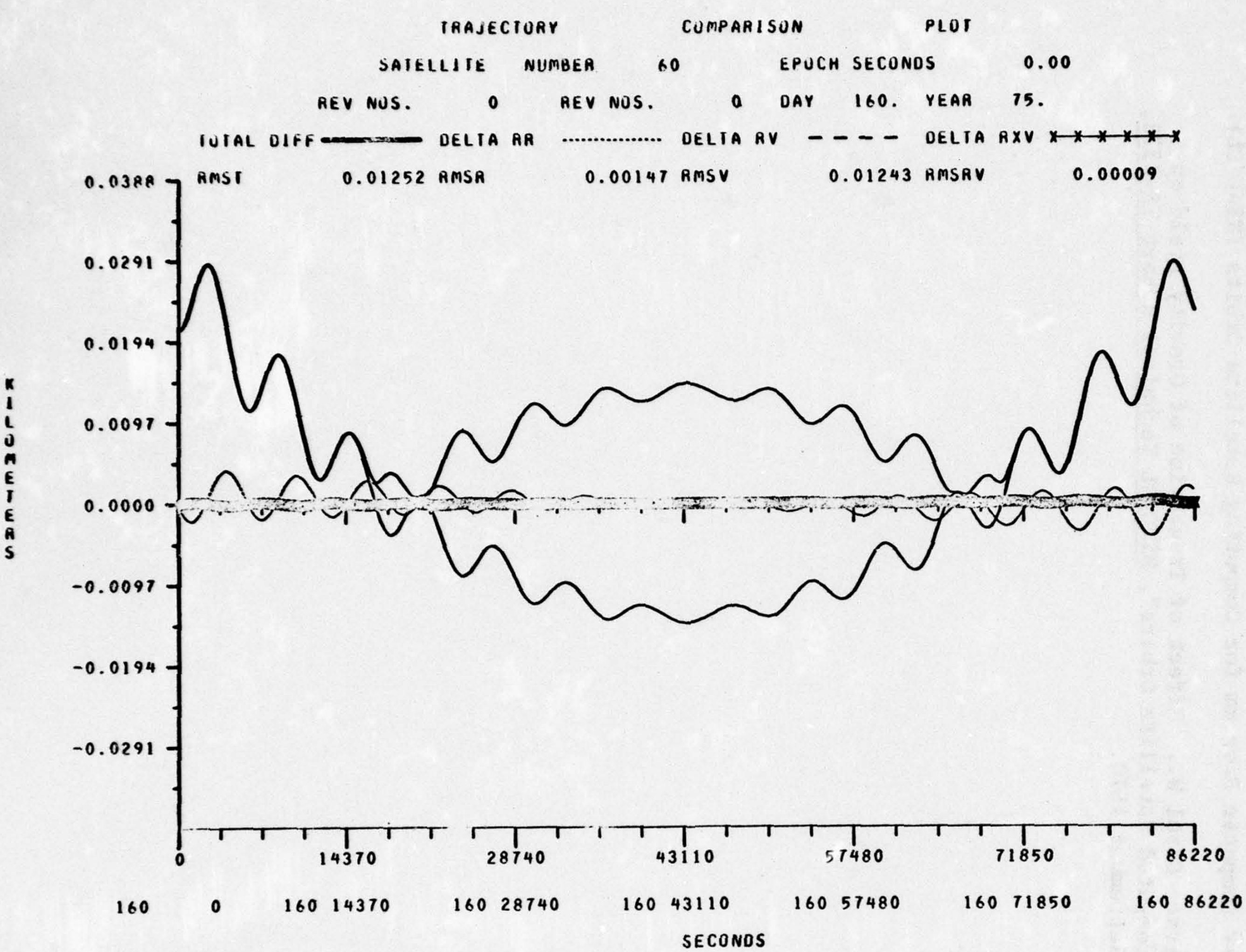

FIGURE 2 30 Sec. vs. Best Fit Residual

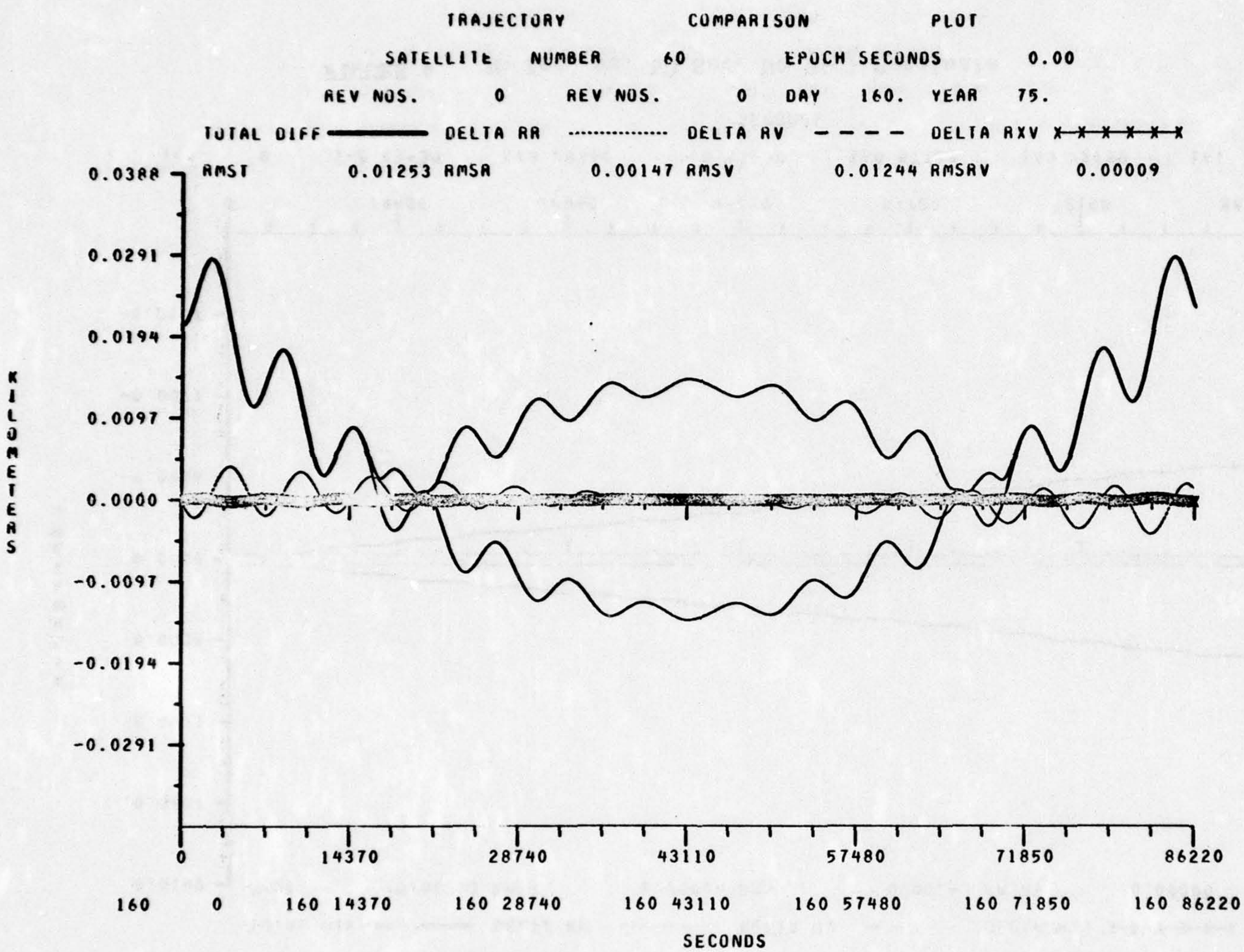

FIGURE 3 60 Sec. vs. Best Fit Residuals

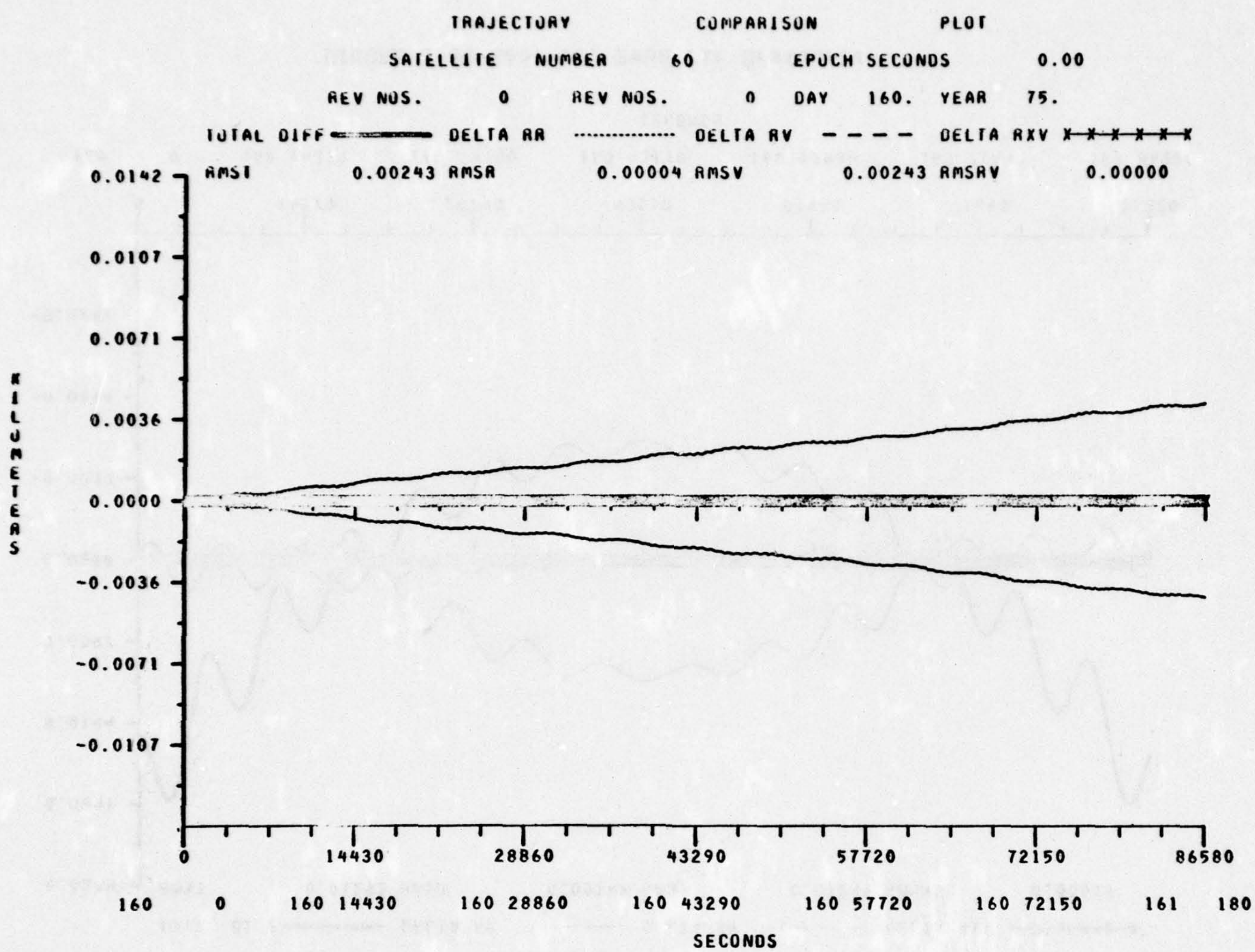

FIGURE 4 30 Sec. vs. 60 Sec. No Fit) Resdiuals

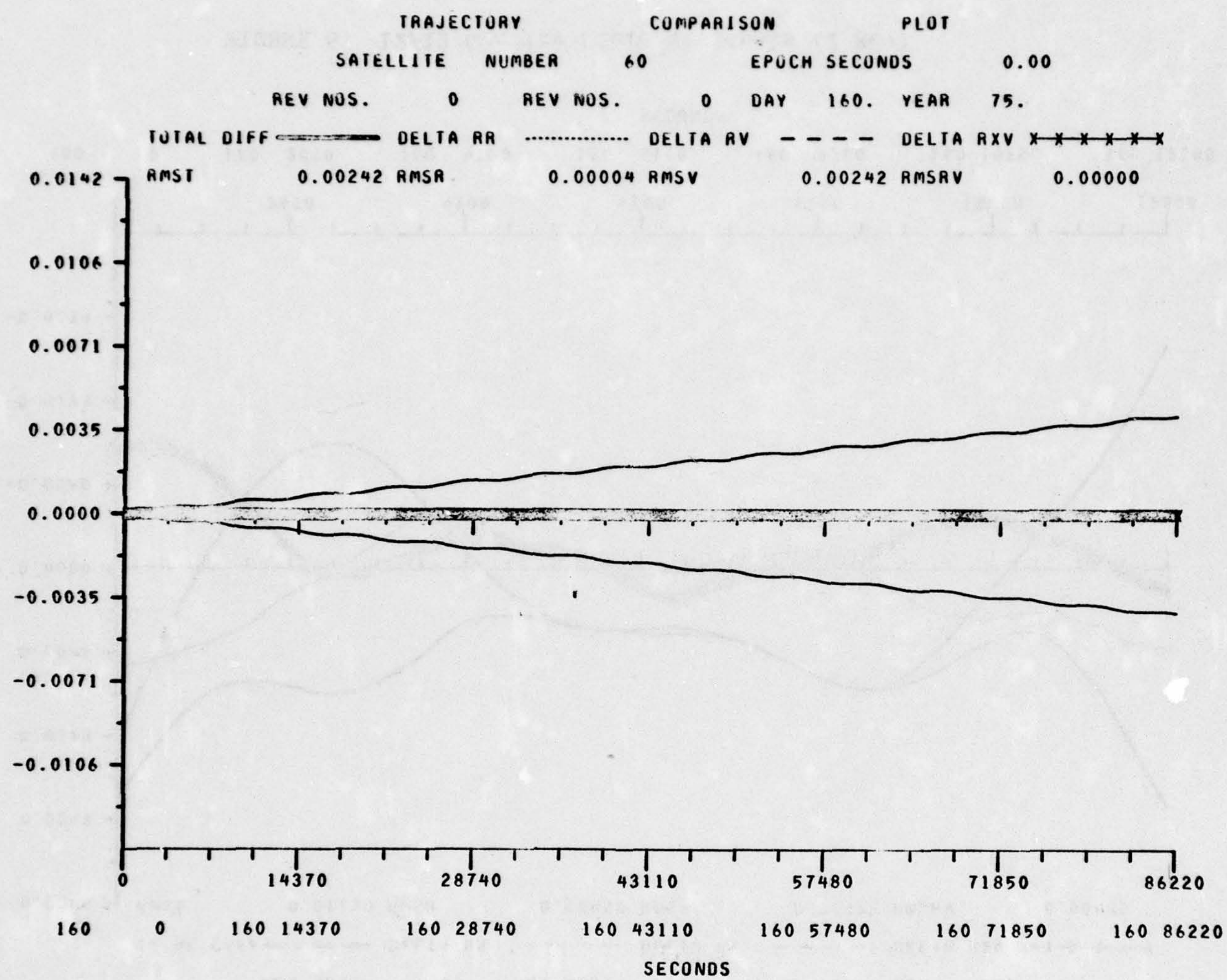

FIGURE 5 30 Sec. vs. 60 Sec. (Both Best Fits) Residuals

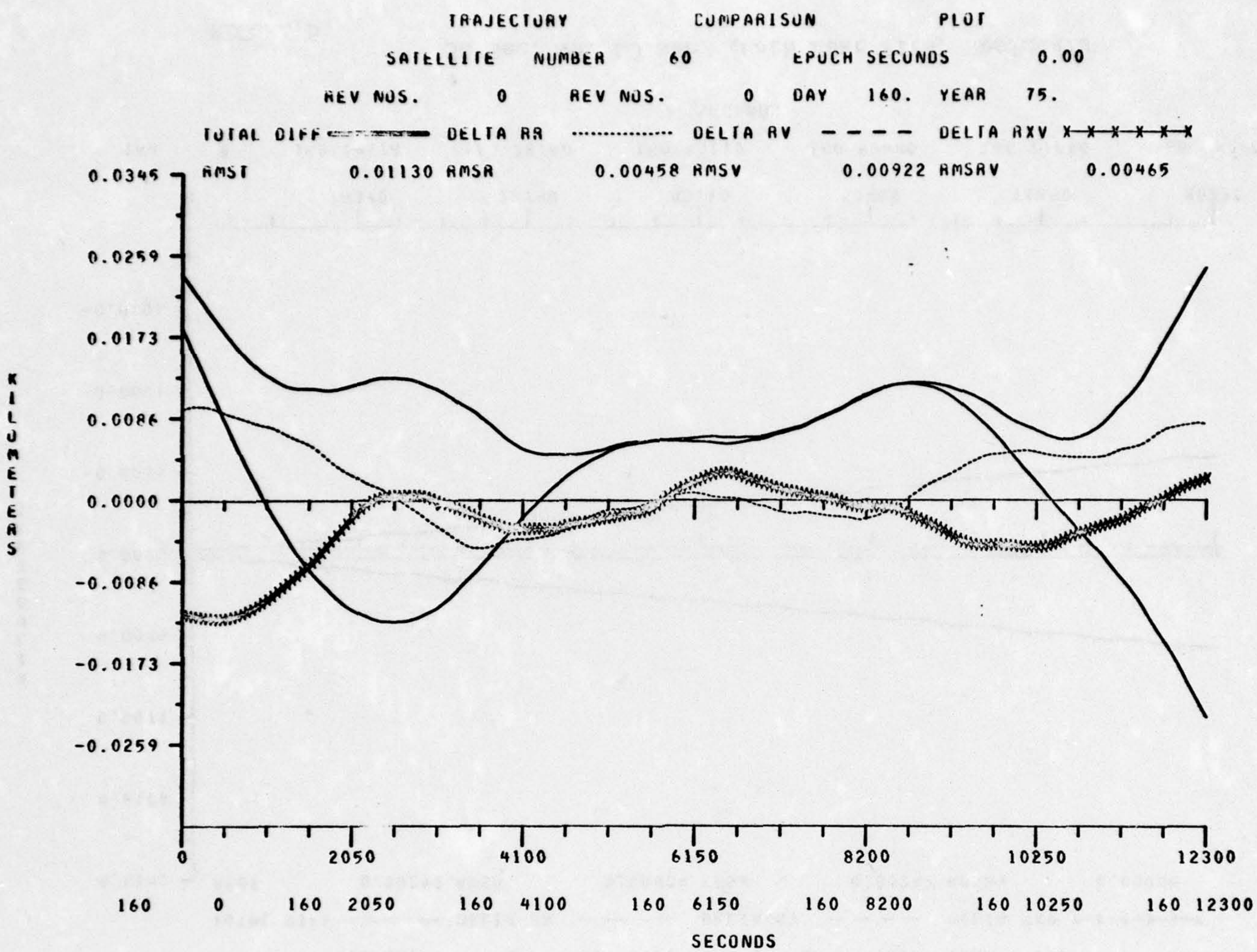

FIGURE 6 12/12 Gravity Field Residuals (2 Rev)

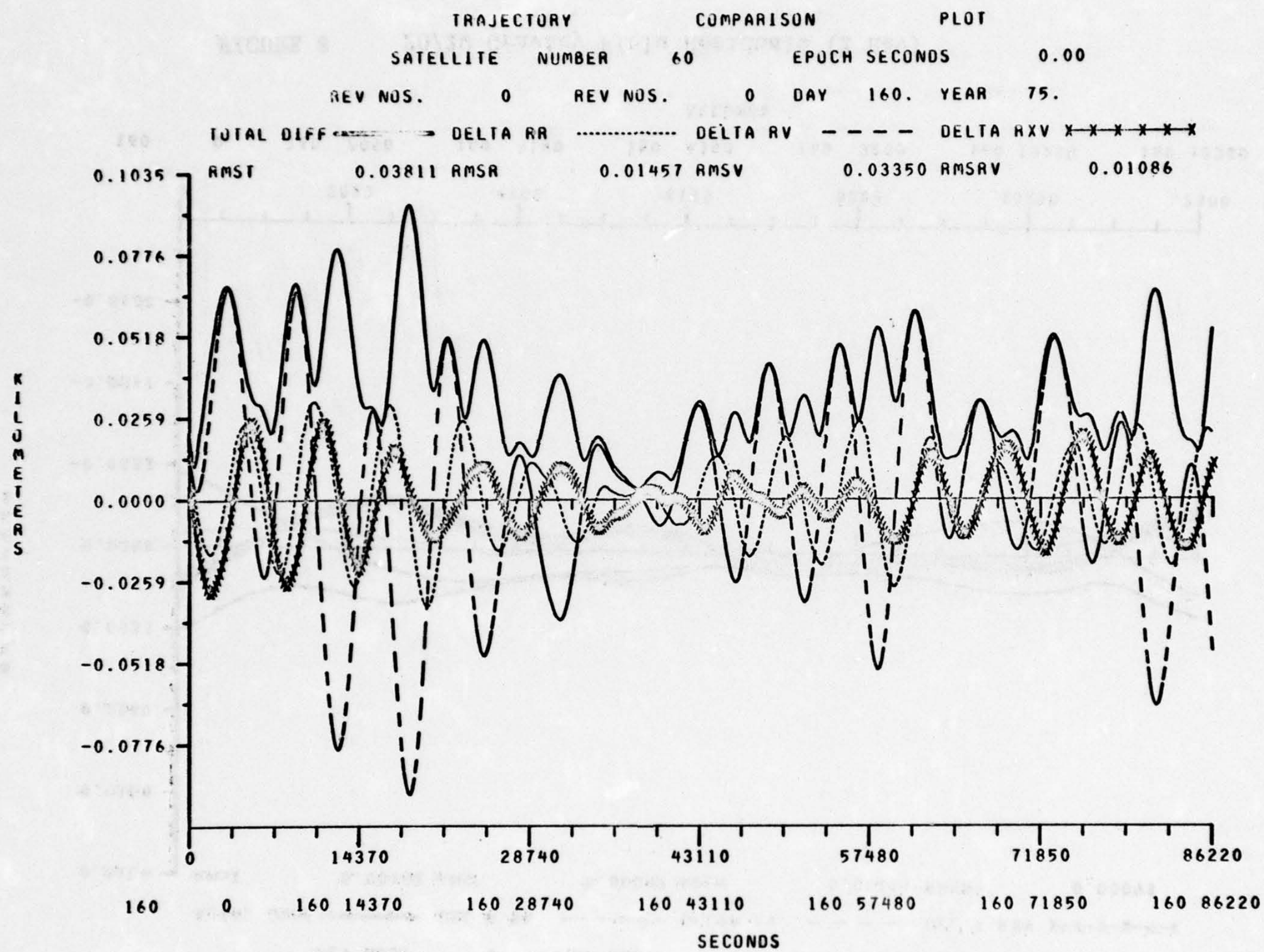

FIGURE 7 12/12 Gravity Field Residuals (24 Hr)

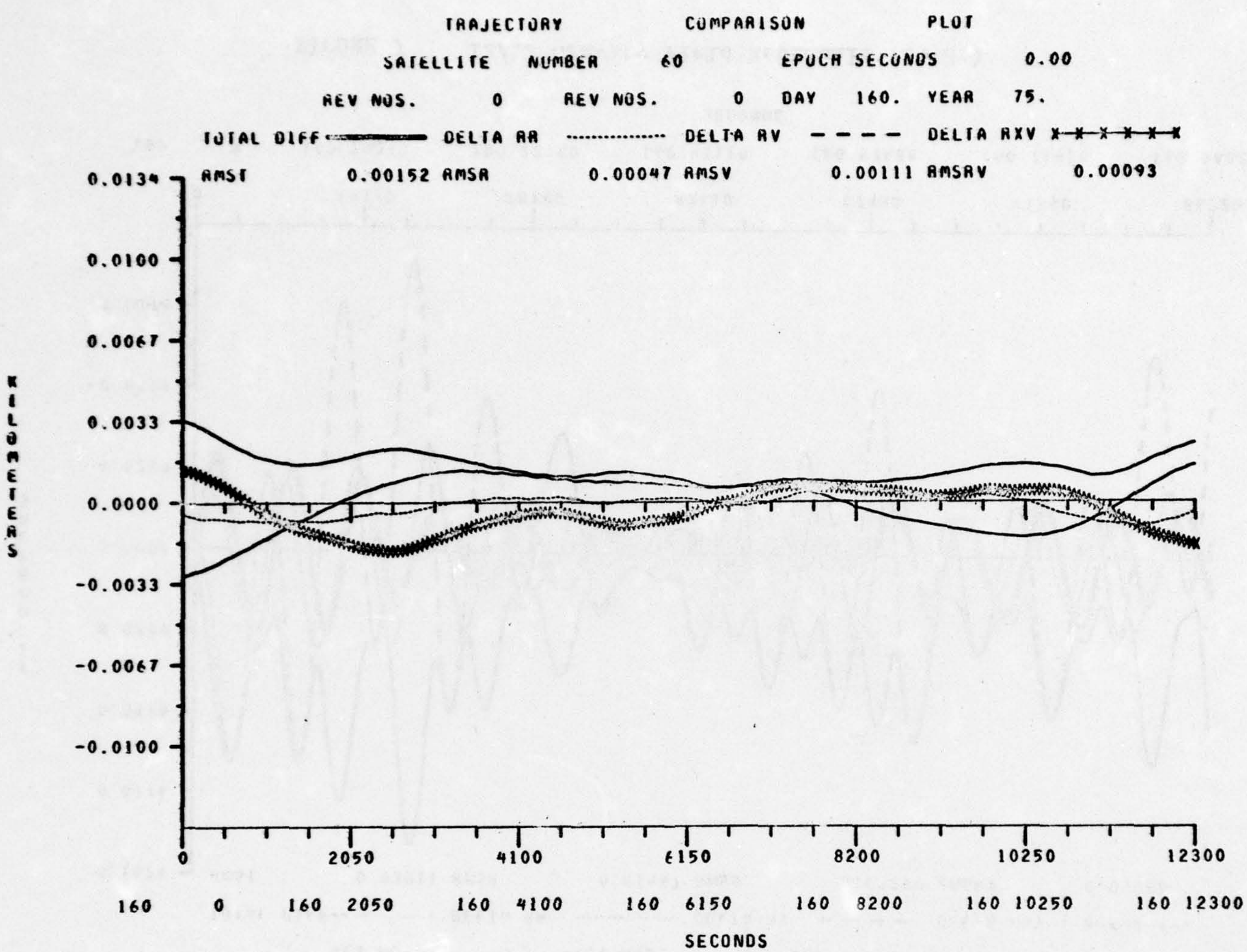

FIGURE 8 20/20 Gravity Field Residuals (2 Rev)

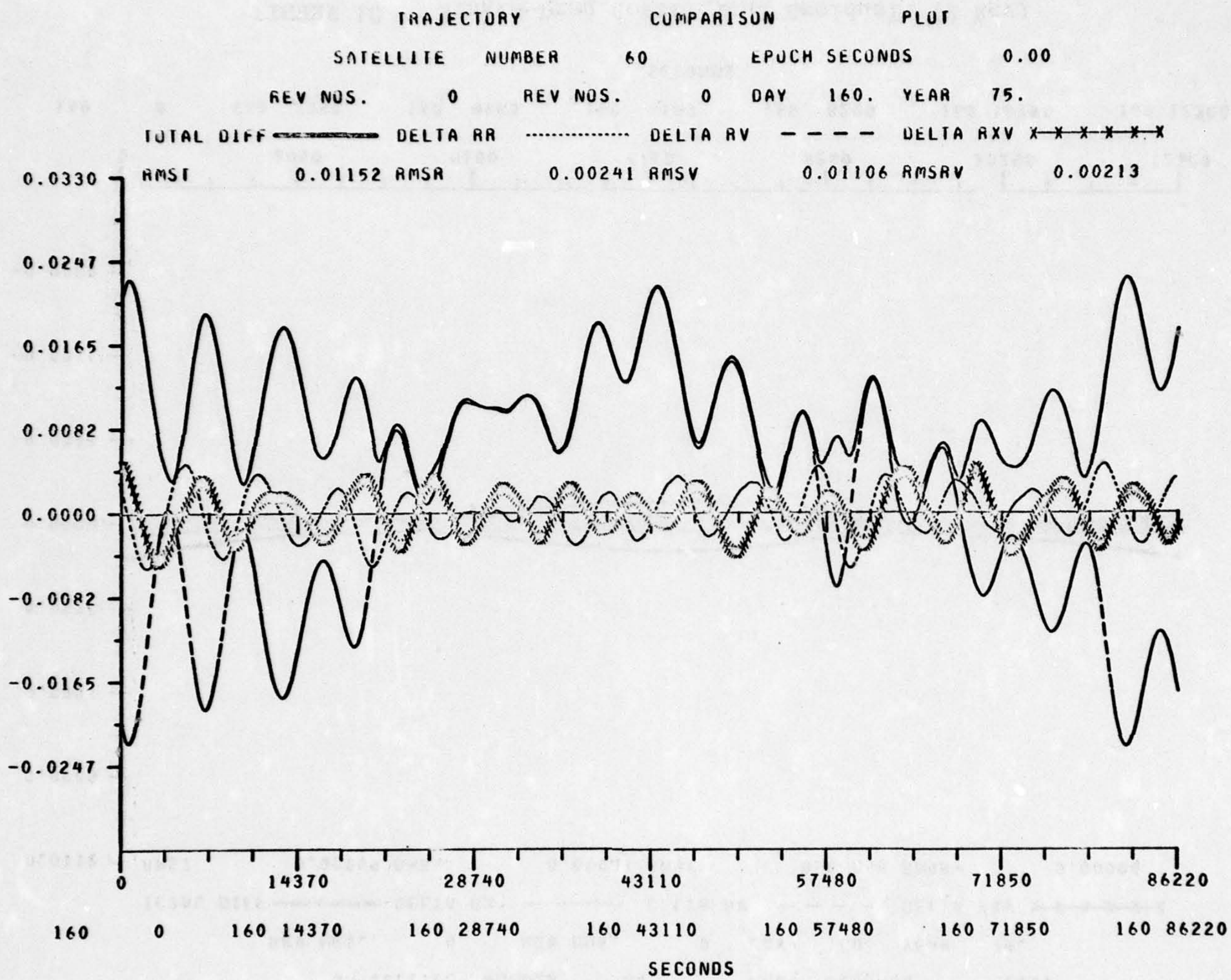

FIGURE 9 20/20 Gravity Field Residuals (24 Hr)

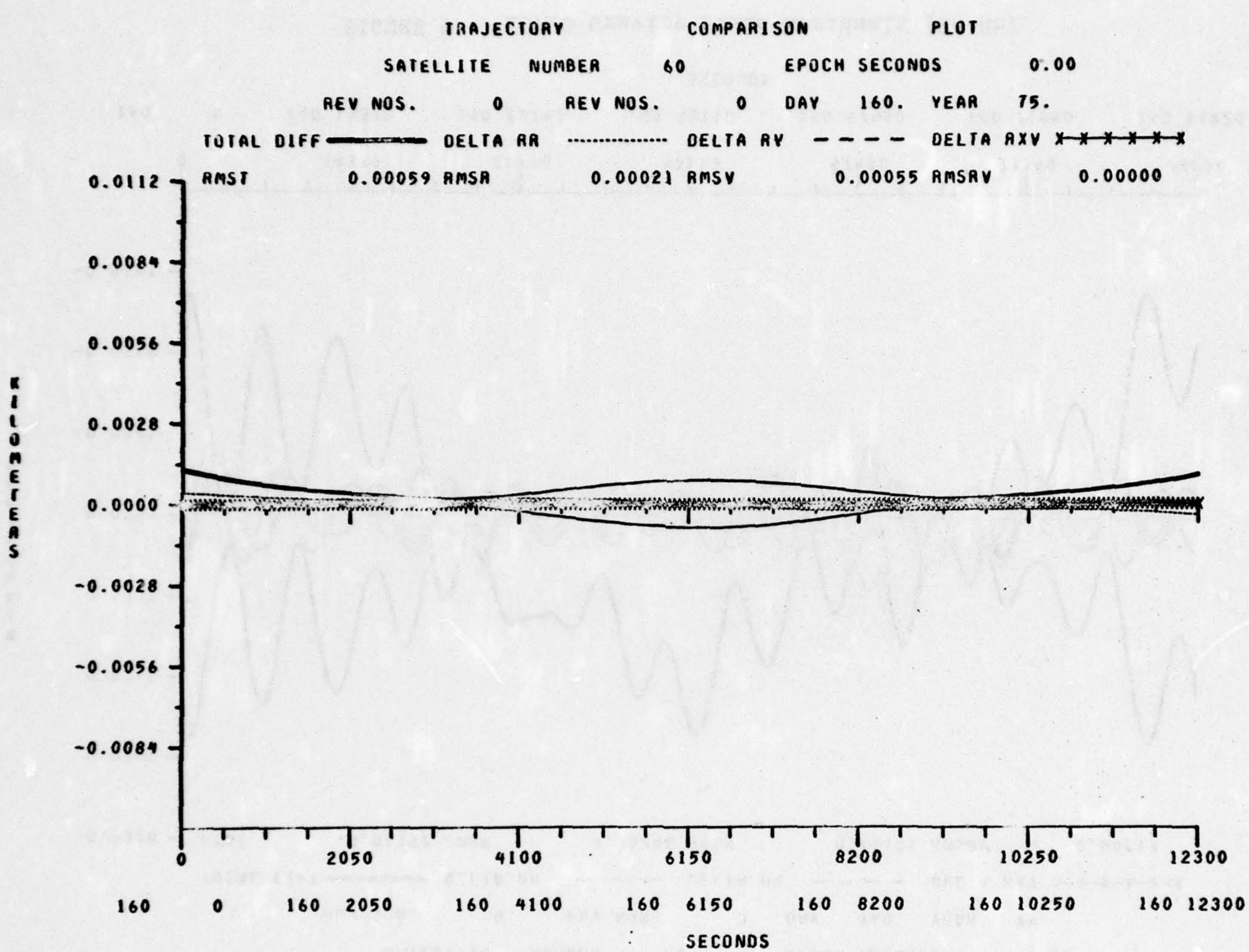

FIGURE 10 Single Drag Coefficient Residuals (2 Rev)

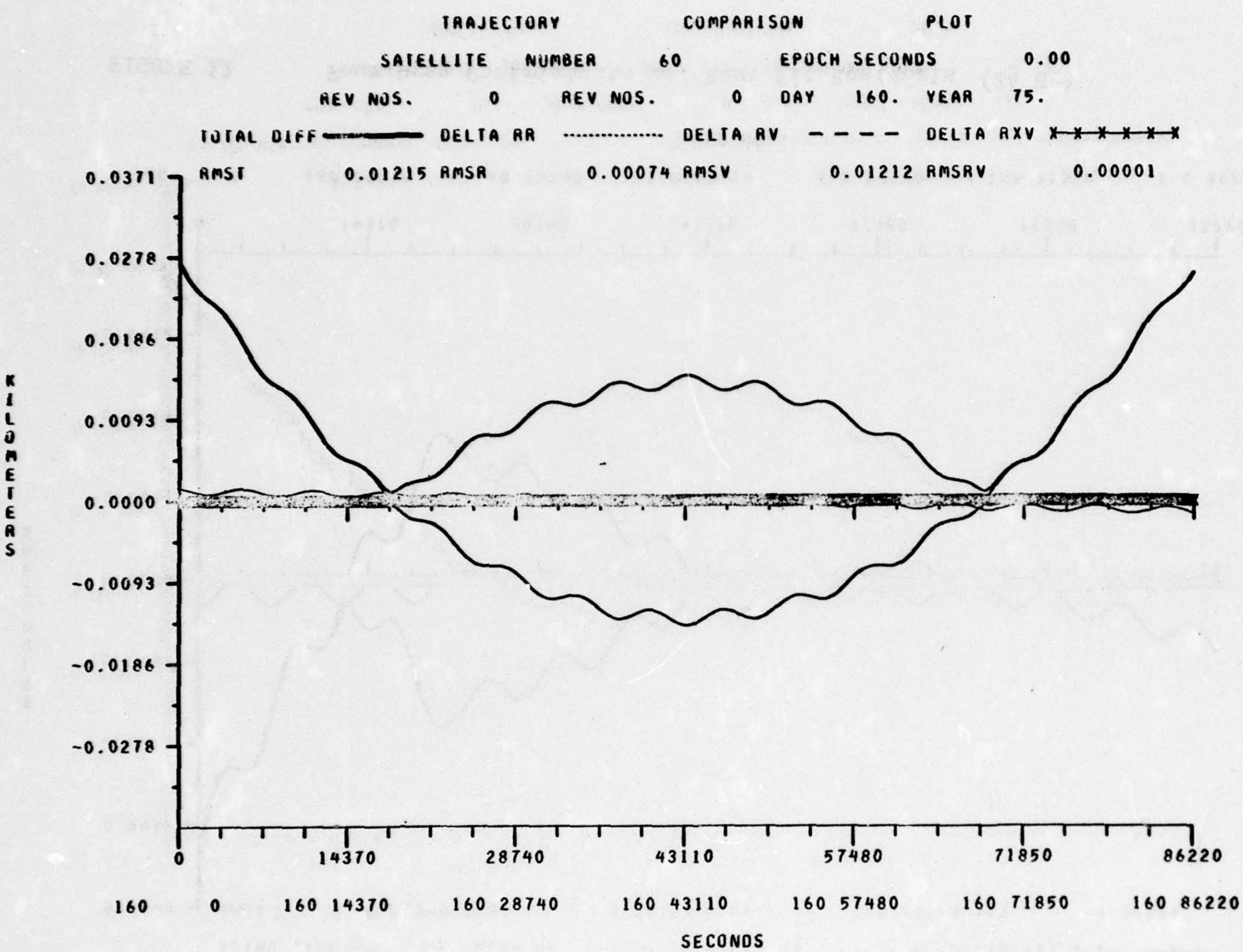

FIGURE 11 Single Drag Coefficient Residuals (24 Hr)

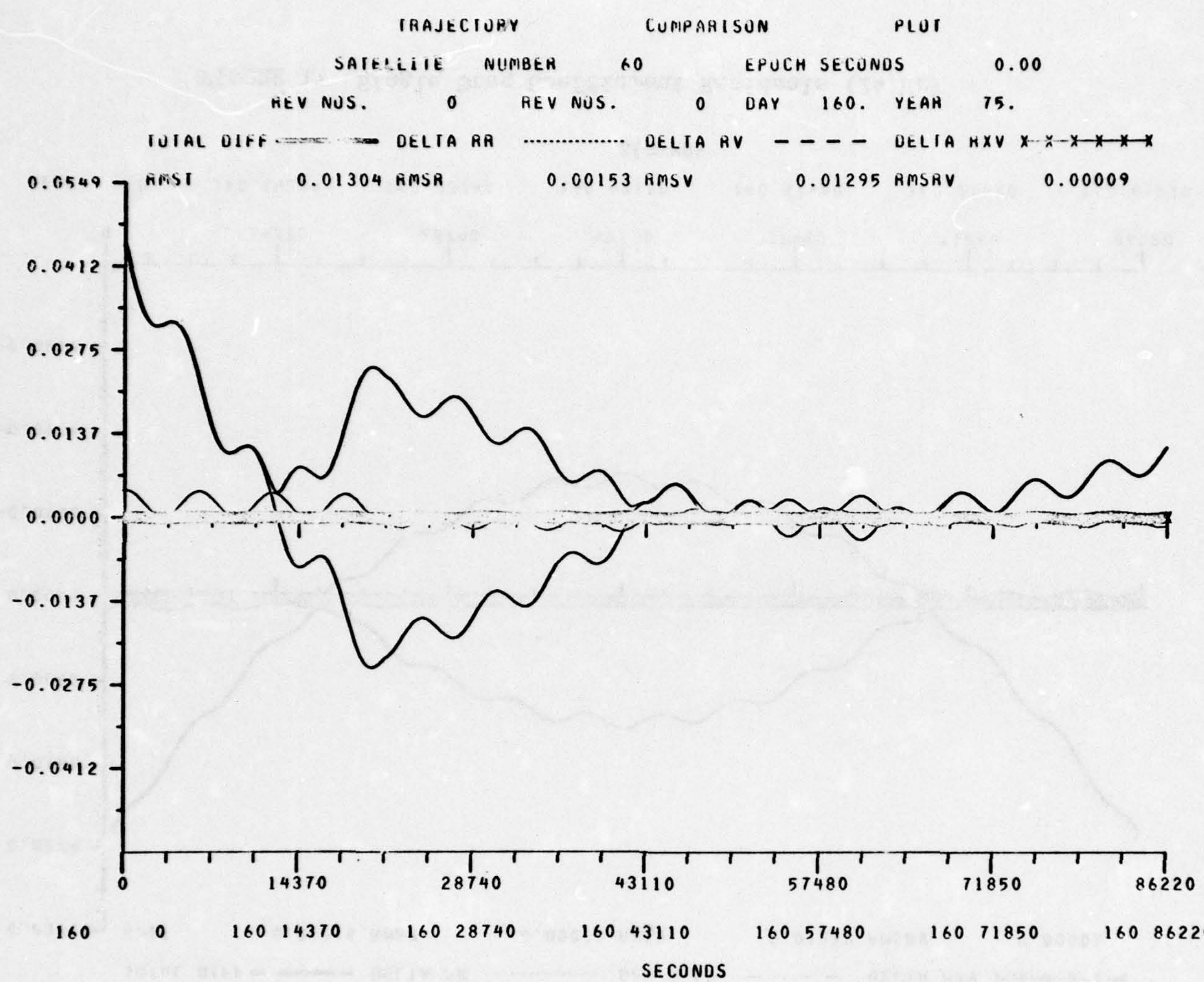

FIGURE 12 Four Drag Coefficients vs. Best Fit Residuals (24 Hr)

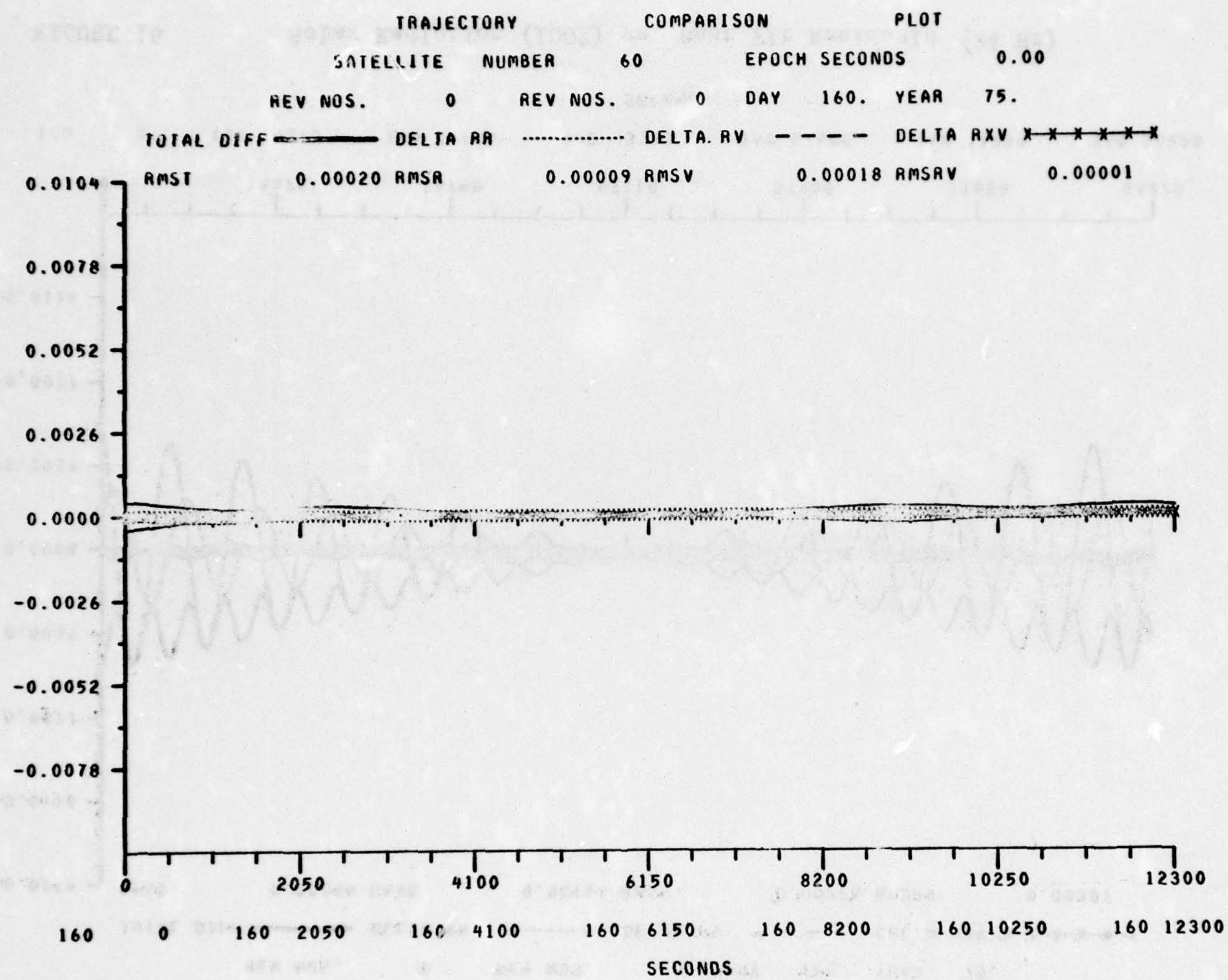

FIGURE 13 Solar Radiation (50%) vs. Best Fit Residuals (2 Rev)

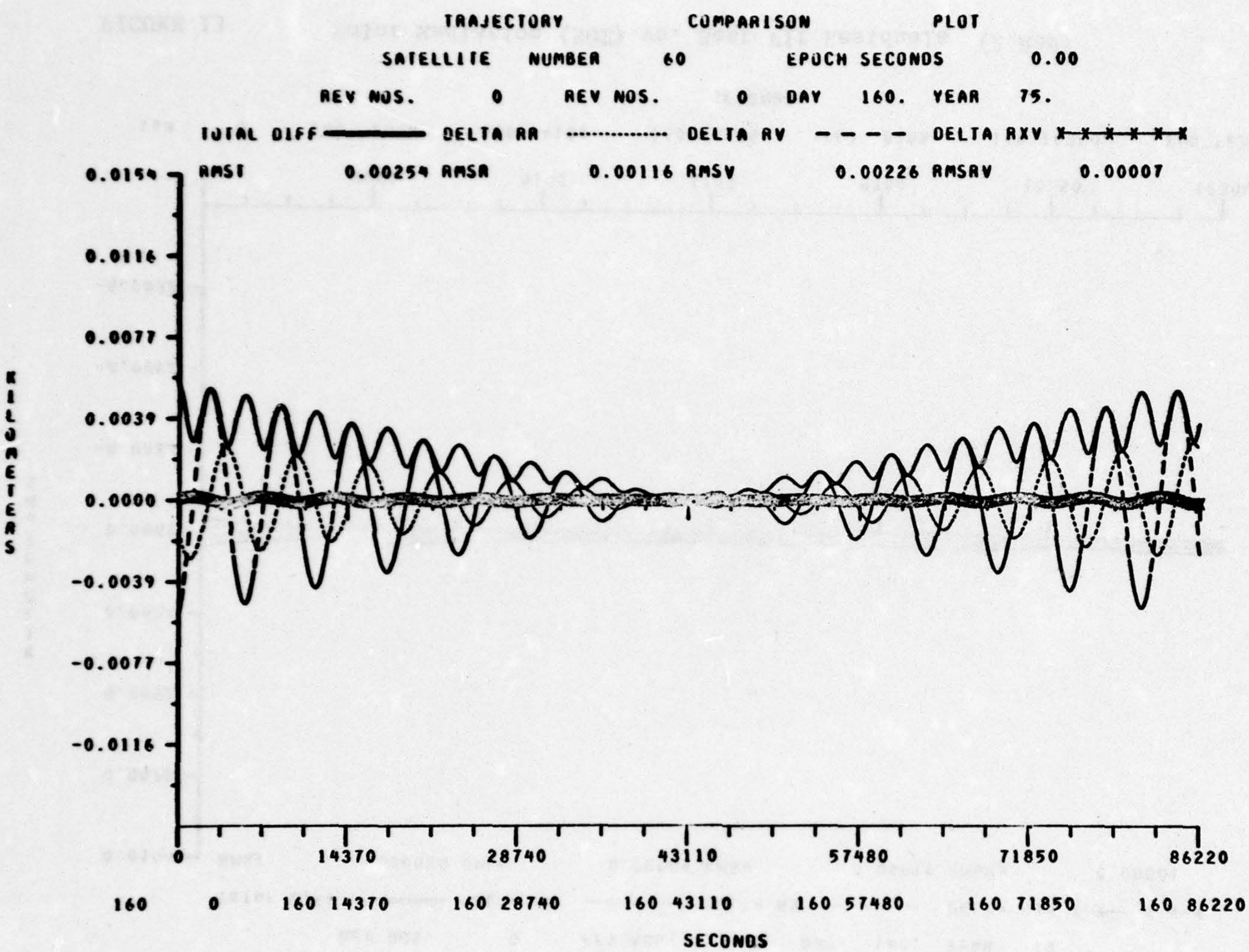

FIGURE 14 Solar Radiation (100%) vs. Best Fit Residuals (24 Hr)

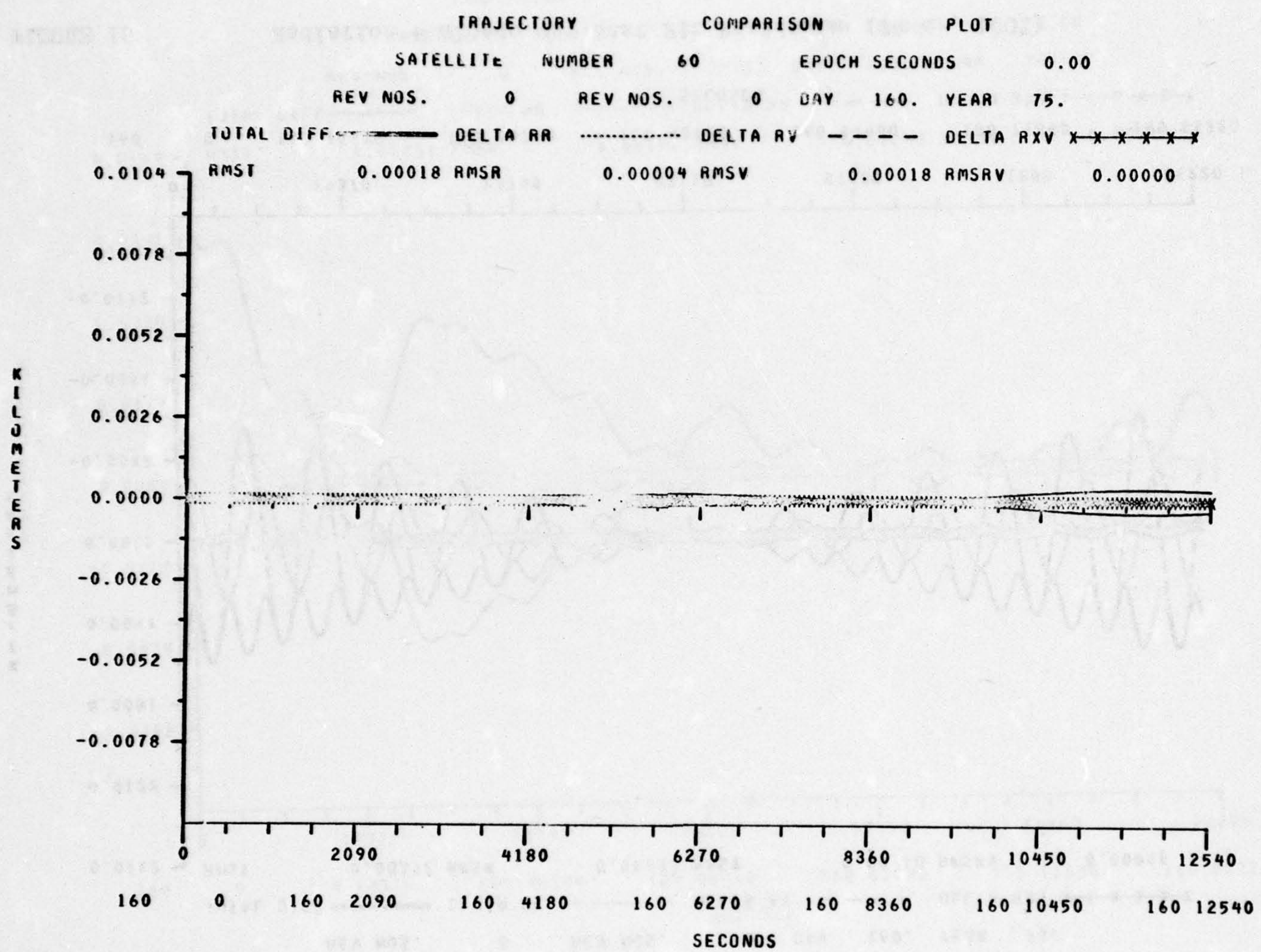

FIGURE 15 Albedo vs. No Albedo Residuals (2 Rev, 50%)

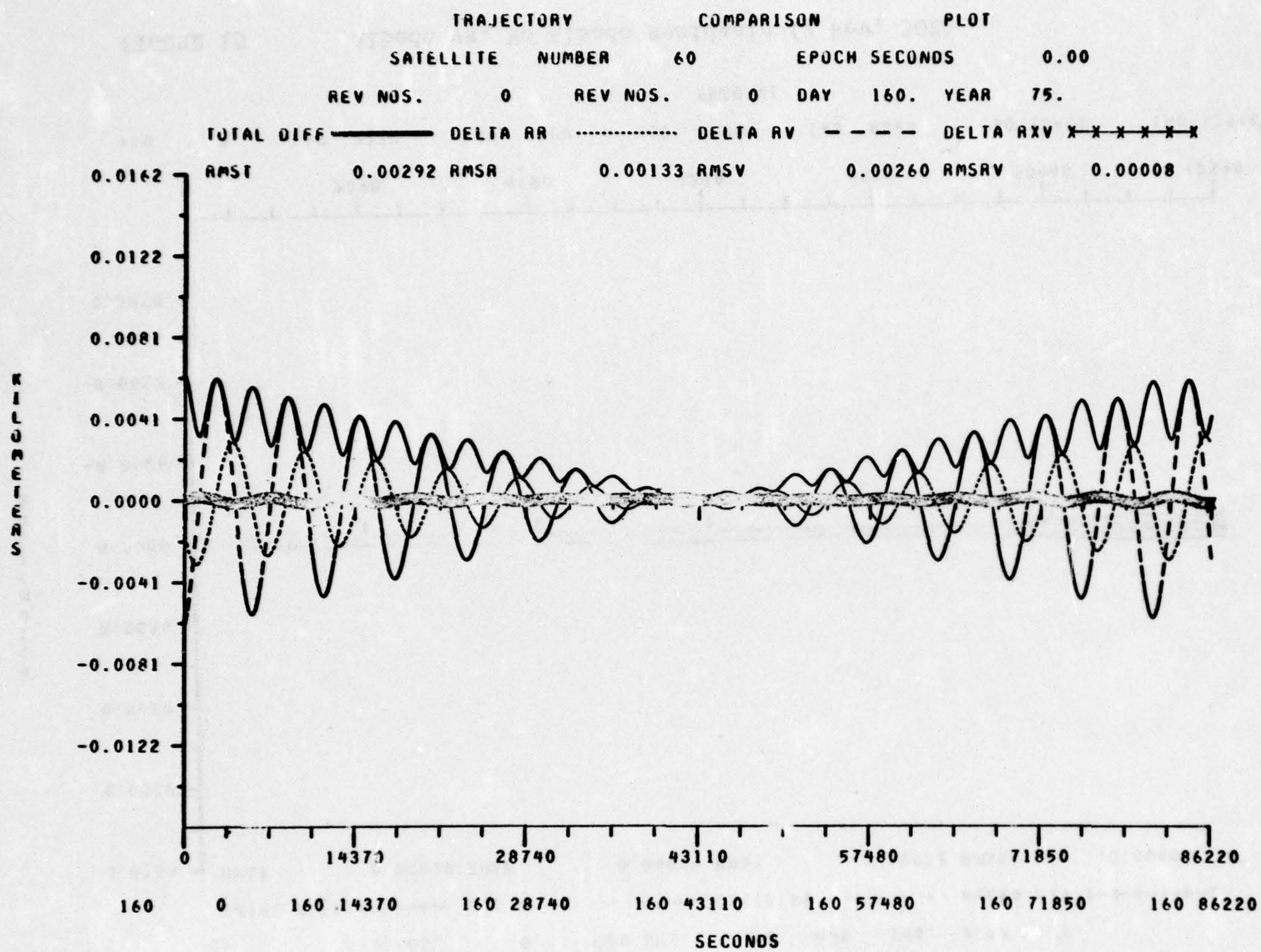

FIGURE 16 Radiation + Albedo vs. Best Fit Residuals (24 Hr, 100%)

Radiation+Albedo + 4 Drag Coefficient vs. Best Fit Resdiuals

(24 Hr, 100%)

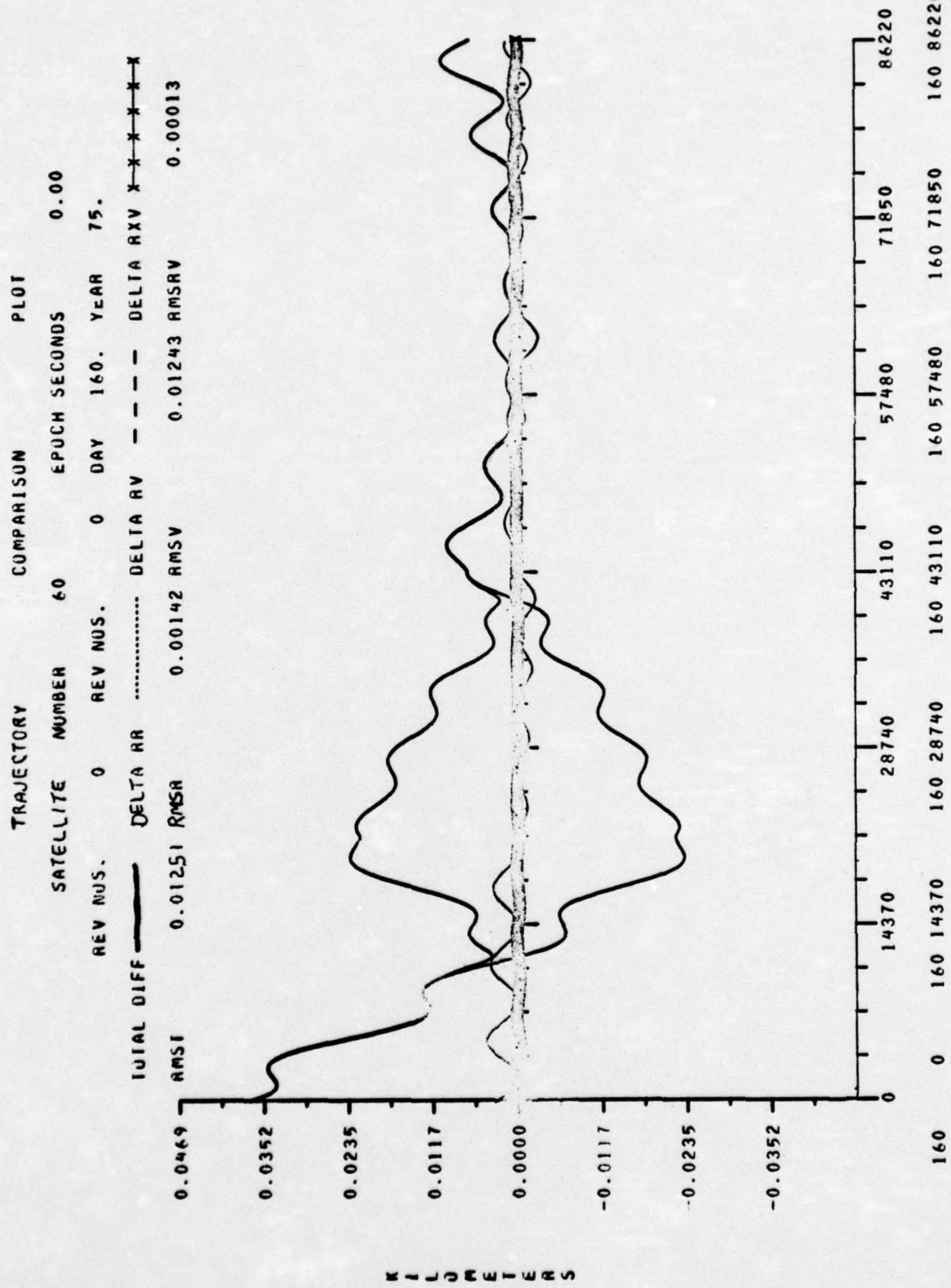

FIGURE 17

FIGURE 17 Radiation + Albedo + 4 Drag Coefficient vs. Best Fit Residuals (24 Hr, 100%)

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